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Format for Project Final Report

I. Report Title, Author, Organization, Grant Number, Date

Tracking experimentally released escaped farm salmon in the Bay of Fundy region to determine recapture feasibility and potential interaction with wild salmon.

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II. A brief (one paragraph) description of the Final Report (for use in the S-K Annotated Bibliography).

We sonically tagged then experimentally "escaped" farmed Atlantic salmon from a cage site in Cobscook Bay, Maine, USA, to document movement patterns and fates of the fish. Cobscook Bay and the surrounding Bay of Fundy region are dominated by intense tidal currents. Fish were liberated in either the winter or spring, which are the peak storm seasons. Tagged salmon dispersed away from the cage sites within a few hours post-release. There were high mortalities of the fish within Cobscook Bay and the surrounding coastal region (56% of winter release fish; 84% of the spring group) probably due to seal predation. Surviving fish exited the coastal zone to the Bay of Fundy primarily by following the dominant tidal currents in the region through Canadian waters. One fish showed an extended course track running from the release site down to the Narraguagus River estuary, then returning to the release area where it meandered extensively back and forth across the US Canada border. No sonically tagged fish were detected during the autumn spawning season in any of 40 monitored Atlantic salmon rivers draining to the Bay of Fundy. The results suggest that in this region farmed salmon cannot be effectively captured after an escape, and that few farmed salmon released in winter and spring will survive to spawn with wild fish. However, maturing fish escaping in autumn may survive long enough to pose a significant introgression risk. In addition, the extended course track of one fish raises concerns about its possible impacts if it had been a disease carrier. Continued attention to containment methods and disease control at farms is warranted.

III. Executive Summary

A brief and succinct summary of Final Report.

We sonically tagged then experimentally "escaped" farmed Atlantic salmon from a cage site in Cobscook Bay, Maine, USA, to document movement patterns and fates of the fish. Cobscook Bay and the surrounding Bay of Fundy region are dominated by intense tidal currents. Fish were liberated in either the winter or spring. Tagged salmon dispersed away from the cage sites within a few hours post-release. There were high mortalities of the fish within Cobscook Bay and the surrounding coastal region (56% of winter release fish; 84% of the spring group) probably due to seal predation. There was no evidence for size-specific mortality in the fish that died, although the range of size in the fish tagged was small.

Movements of the fish out of the coastal region to the Bay of Fundy were generally rapid (on average 8.3 days for the winter release fish, and 4.4 days for the spring release fish. Surviving fish exited the coastal zone to the Bay of Fundy primarily by following the dominant tidal currents in the region through Canadian waters. However, some fish were entrained in the region for several tidal cycles, fluxing up and down the principal water channels in the region for variable periods of time. One fish showed an extended (181 d) course track running from the release site down to the Narraguagus River estuary, then returning to the release area where it meandered extensively back and forth across the US Canada border.

No sonically tagged fish was detected during the autumn spawning season in any of 40 monitored Atlantic salmon rivers draining to the Bay of Fundy in the year of release (2004). The fish used in the experiment had been reared to the smolt stage at a hatchery in the Magaguadavic River. Previous work with escapees at this river showed that adult salmon could have a homing tendency to this stream (Whoriskey and Carr 2001). We maintained a limited array of receivers in the Passamaquoddy Bay region and the Magaguadavic River, through the spawning season of the second year (2005) after the experimental fish had been released. None of the experimental fish were detected in the original release area, or entering the Magaguadavic River.

Some of both the winter (six) and spring (25) released salmon entered the tidal zone of Dennys River, which drains into Cobscook Bay near the release site, shortly after either the winter or spring release. The Atlantic salmon of the Dennys River are listed as endangered. None of the experimental animals penetrated into freshwater zone. Six additional fish (three each from the winter and spring releases) were recorded on the sonic receiver arrays in the region of the Narraguagus River. Again, none of these fish entered fresh water.

The results suggest that farmed salmon escaping from cages in this area virtually immediately disperse from their cage sites. Thus there is little probability of quickly recapturing them post-release.

The results also indicate that fish escaping during the winter and spring will survive poorly, and/or disperse away from the region. This will limit ecological and genetic interactions with endangered wild salmon populations. However, we remain concerned that a late summer or early autumn escape of farmed salmon nearing maturity could result in enough fish surviving that significant numbers could enter rivers and genetically introgress with wild fish. In addition, we documented an extended, several month long course track for one fish that exited the study area, moved to the estuary of the Narraguagus River, then returned to the study area where it wandered extensively back and forth across the US/Canada border before we lost it. If this fish had been a disease carrier, it could have spread the disease over a very large area, including into the range of endangered salmon populations. This argues for continued attention to and improvement of containment methods and disease control at farms. These can build on the significant improvements that have already been made with containment at fish farms in this region (e.g., Goode and Whoriskey 2003), and which have substantially reduced the number of escapees entering indicator rivers in the region (Whoriskey et al. Ms. submitted).

IV. Purpose

A. Detailed description of problem or impediment of fishing industry that was addressed.

Following the listing of Atlantic salmon populations of the Maine Distinct Population Segment (DPS) as endangered (e.g., NRC 2004), the potential interactions between the wild salmon and escaped farm salmon in the Downeast region were viewed as a factor that could be harming the recovery effort for the wild fish. In particular, there is great concern that domesticated strains of farmed salmon of variable genetic origins (none of which were native to the Downeast listed streams) could spawn with wild salmon, introducing characteristics maladapted for the wild. This could reduce the survival of the hybrids, dilute the pure wild-strain gene pool, and if farmed fish spawned with other farmed fish potentially put pure farm-origin juvenile salmon into streams to compete with wild parr. Research in Europe in salmon farming regions has shown that all of these interactions can occur, and reduce the survival of wild salmon (Fleming et al. 2000, McGinnity et al. 2003).

Our understanding of the movements and fate of the escaped farmed salmon in the Fundy region was poor. The region is one of intense tidal currents, however, there is also symmetry to the ebb and flow of the tides that results in the retention of water particles within the region for variable times (14 days for the Passamaquoddy Bay regions, and over 70 days for the Bay of Fundy at-large; Chevrier and Trites 1960). Thus, the fish could be rapidly dispersed by the tidal currents, or alternatively remain in the region and flux up and down with the tides. If the fish remained localized for enough time, then there might be a possibility to recapture them following escape events. If they dispersed and survived, then they would have the potential to enter rivers in the region and genetically introgress with wild fish.

The research was conducted to provide information about the movements and fate of escaped farm salmon. This can be used to better understand the possibility of interactions between wild salmon and escaped farm salmon, and to develop appropriate mitigation measures that on the one hand protected the ESA listed wild salmon, and on the other provided a cost-effective and appropriate response on the part of the important salmon farming industry located in this area.

B. Objectives of the project.

The objectives were to:

- Document the time it took for the escaped farmed salmon to disperse away from their cage site in the coastal zone, to offshore areas of the Bay of Fundy.

- Track the directions and rates of any movements that the fish exhibit, and correlate them with tidal currents and other environmental cues.
- Determine rates of mortality of the escaped fish in the coastal zone.
- Document the degree to which escapees from the release site crossed the international border into Canadian waters.
- Determine if any experimental fish moved to rivers during the autumn spawning season. in the region at spawning time.

V. Approach

A. Detailed description of the work that was performed.

Following approval of our protocols by the US government, farmed salmon were obtained from a site in Cobscook Bay belonging to Heritage Salmon (Fig. 1). The fish in the sea cage site were grown to the smolt stage in a hatchery on the Magaguadavic River, St. George, New Brunswick. Two experimental "escapes" were initially planned, one in the autumn and one in the following spring. Both releases would use fish of the same smolt class. However, the autumn release was moved into the winter period, due to delays that occurred in completing the environmental review process that was required before permission to make the releases was granted.

Fish were captured in the sea cages by baiting them with feed pellets into long handled dip nets. Captives were placed in insulated holding tanks on a barge moored next to the cages. Tents were erected on the same barge to provide sheltered surgical theaters for the insertion of the tags.

Experimental fish were anesthetized with clove oil (40 mg/l), and a small incision with a sterilized scalpel was made in the abdomen to insert Vemco (Shad Bay, Nova Scotia) model V-13 tags (36 mm length, weight in water 6 g). Each tag had a minimum battery life of 360 days and emitted a unique coded signal, letting us identify individual fish. Tags were sterilized before insertion, and the wound was closed with two to four stitches. Following surgery, the fish were rapidly transferred to a well oxygenated insulated tank for recovery, and were held there until their release. Surgery in the winter occurred on the 12th (N = 49) and 13th January 2004 (N = 26), with fish released on the same days after an 8 h recovery period. Spring surgeries occurred on 29 April (N = 21), 30 April (N = 50), 6 May (N = 48), 7 May (N = 50) and 13 May (N = 27), with releases again occurring about an 8 h recovery period. The holding of the fish on the sites post-operation had to be minimized due to a fear that stress could bring on an infectious salmon anemia virus problem.

We attempted to release fish in batches on falling and rising tides, during both the day and the night. A total of 198 fish were released in the spring, and 75 in the winter. We had planned to implant tags in about 200 fish in both the inter and the spring, however, a bitter cold snap intruded in the winter and dropped water temperatures rapidly into the range of 0°C. At these temperatures, the combination of anesthesia and surgery proved lethal to test fish, so we abandoned any further tagging attempts after 75 fish had been successfully released.

Vemco VR2 receiver units were moored in 40 rivers draining to Bay of Fundy region, and 60 in arrays within the coastal zone (Fig. 1). In rivers, the receivers were placed in areas where a single receiver had the range to detect all fish passing by (e.g., narrow, deep, slow flowing pools in freshwater above the river estuary). In the coastal zone, the receivers were laid out in arrays, taking advantage of narrow channels among the islands and mainland so that a minimum number of receivers could cover all fish passing by. Detection ranges for the receivers is as good as > 1 km in this region (e.g., Lacroix *et al.*, 2004; and from our own experience). We placed our units at distances of 800m or less from each other. This generally resulted in an overlap in the detections by two receivers when a fish passed in the middle area between them. We also exchanged information with NOAA Fisheries Service research teams (J. Kocik, T. Sheehan, and collaborators) that were conducting independent sonic telemetry work in Maine and who had deployed receivers that had picked up some of our fish. For their work they had VR2 arrays within the Dennys River, which drains into Cobscook Bay, and in the estuary of the Narraguagus River in Downeast Maine, about 40 km south west of the Machias River (see Fig. 1), and 100 km via the most direct water route from our release site.

When a tagged fish emitted a signal within the range of a receiver, it recorded the tag number, the time of day, and date of the reception. Receivers were visited periodically to download information stored on them, and to replace any units that had been lost. Many licenses for scallop (177) and urchin (66) draggers are issued in this region by Canadian or U.S. authorities, and inevitably receivers were lost to the fishery, and had to be replaced. In some cases, this resulted in gaps in our course tracks for individual fish.

Any fish that passed through the array lines located at either the Lubec Narrows or Head Harbor passage (Fig. 1) was considered to have left the coastal zone and entered the Bay of Fundy. Fish whose tags were located by passive or active tracking in the same location for more than a week, and which subsequently failed to log on to any other receiver units out of this fixed position over the course of the study were classified as dead.

Four of the receivers were placed at the farm site, one at each at the corners of the rectangle formed by the cage placements at the site. These recorded the time to dispersal of the fish post-release to a distance of about 1 km from the cage site. Once fish disperse farther than this, we judged that the chances a fish farmer would have to recapture them in the case of a real escape would be minimal.

In addition to the use of the moored VR2's, we conducted active tracking throughout the year with a Vemco VR60 hand-held hydrophone. We used both omni-directional, and directional hydrophones. Attention was particularly focused on areas where harbor (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) were seen hauled out, and where they might have excreted or discarded tags of any farmed salmon that they had caught. A number of tags located in these areas were only detectable at high tide, presumably because they were out of the water during low tide periods.

Data were analyzed with PC SAS, or the Microsoft Excel Data analysis function.

B. Project management: List individuals and/or organizations actually performing the work and how it was done.

The scientific work was conducted by the Research and Environment Department of the Atlantic Salmon Federation. The field team included Dr. Fred Whoriskey, and Biologists Paul Brooking (BSc.), Gino Doucette (BSc.), Steve Tinker (MSc.) and Jon Carr (MSc.). Financial accounting and reporting was conducted/overseen by Mr. William Mallory, the Atlantic Salmon Federation's chief financial officer.

VI. Findings

A. Actual accomplishments and findings.

Once released, fish rapidly dispersed away from the cage sites, although spring fish were significantly slower to disperse than the winter release fish ($p < 0.05$). Times to last detections by the receivers at the cage sites in winter averaged 2.4 h +/- 2.4 h (range 0.01 – 14.4 h, N = 75) for the winter released fish, and 5.76 h+/- 21.1h (range 0 – 182.2h, N =184) for the spring released fish.

Mortality of the fish in the coastal zone varied depending on the season in which they were released, but were high. In winter, 42 of 75 fish (56%) died before they could exit to the open sea. By contrast, 167 of 198 (84%) spring fish died in the coastal zone, a significant difference ($\chi^2 = 7.6$, df=1, $p < 0.05$).

Most dead fish that we located from both release periods were found in Cobscook Bay (winter releases: 31 of 42 mortalities, 74%; spring releases: 154 of 167 mortalities, 92%). The difference between the two periods was not statistically significant ($\chi^2 = 2.06$, df = 1, $p > 0.10$).

There were no significant differences in the sizes of the fish that survived to exit to the ocean, or died, during either the winter or spring releases ($P > 0.05$). Winter release fish averaged 48.1 +/- 3.4 (SD) cm fork length (range 39 – 55 cm), whereas the spring released fish that had had more time to grow were significantly larger (51.1 +/- 2.6 cm fork length, range 40 – 58 cm, $P < 0.05$) at their time of release.

Movements of the surviving fish away from the coastal zone were generally rapid. The time it took to move out of Cobscook Bay in winter (7.4 +/- 31.3 days, range 0.1 – 181 d, N = 33) did not differ significantly from the time it took to leave the Bay in the spring (1.6 +/- 2.1 d, range 0.03 – 6.7 d, N = 22; $P > 0.05$). For fish that survived to exit the coastal zone, it took 8.3 +/- 26.6 d (range 0.1 – 143 days, N = 28) in winter, and 4.4 +/- 4.7 d, range 0.3 – 19.4 d, N = 20; $P > 0.05$) to get from the cage site to the Bay of Fundy. Some fish moved directly out to sea, whereas others had complex course tracks (Fig. 2), probably because they became entrained in the complicated tidal circulation of the region.

The apparently much higher values for the time to exit for winter compared to the spring groups are due to the behavior of a single winter-released fish (No. 2084, see below). If this individual is excluded from the calculation of the winter release statistics, then the time to move out of Cobscook Bay for fish released in this period averaged 1.91 +/- 2.7 d (range 0.1 – 10.8 d, N = 32), and the time to move from the cage site out to the Bay of Fundy was 3.3 +/- 3.2 d (range 0.1 – 11.7 d, N = 27).

Of the fish that exited to the open sea, the great majority (24 of 27 winter release fish, and 21 of 24 spring release fish) did so via the Head Harbor and Quoddy River passages. The dominant tidal circulation occurs through these passages (Chevrier and Trites, 1960), and they are also in Canadian waters. A total of six fish (three each from the winter and spring releases) entered the Bay of Fundy through the Lubec Narrows and south of Grand Manan Island. These fish may have remained exclusively in US waters during their passage.

No tagged fish were detected in the autumn 2004 spawning season entering any of the rivers that were fitted with receivers, including the Magaguadavic River where the hatchery in which they were reared to the smolt stage was located. We continued the receiver coverage of the Magaguadavic River during autumn 2005, but again none of the escapees were detected.

Some of both the winter (six) and spring (25) released animals were detected in the estuary of the Dennys River, a river that drains into Cobscook Bay and which houses a wild Atlantic salmon populations that is officially listed as endangered in the USA. The intrusions typically occurred shortly after the releases had occurred (within 1-2 weeks), and the fish stayed below the head of tide. All six of the winter fish, and 18 of the spring fish, perished within this tidal water. Seals were frequent in the region.

Three other individuals left the study area, and were subsequently detected on a National Marine Fisheries Services acoustic array positioned in the estuary of the Narraguagus River. This river is located about 100 km from the release site by the most direct water access route, and is home to one of the Endangered U.S. Atlantic salmon populations. None of these fish entered the freshwater zone of the river. All three left our study area via the Lubec channel, and may have hugged the coast as they moved south west.

Two fish, one each from the spring (No. 1200) and winter (No. 2084) releases, logged onto the Narraguagus estuary array relatively soon after departure from the study area (75 h and 292 h, respectively). No. 1200 stayed in the estuary array for about 23 h, then moved off and was never detected again. By contrast, No. 2084 (released on January 12, 2004) stayed in the Narraguagus estuary for about 13 hours, then moved back to the study area logging onto receivers near Head Harbor 4.5 days later. This fish remained in the area until July 13, 2004, 181 days post release, wandering extensively then moved out to sea and was not detected again. The third fish left the study area the day it was tagged, and then logged onto the Narraguagus estuary array 138 days post-release. It spent 2.5 h in detection range, and then moved off never to be seen again.

B. If significant problems developed which resulted in less than satisfactory or negative results, they should be discussed.

Equipment loss due to presumed gear conflicts (e.g., draggers in the region destroyed our moorings and released receivers from their positions) caused problems, however we compensated for this by obtaining and redeploying replacement receivers, and having redundancies in our lines. The problems were a financial not a scientific burden, and we succeeded in delivering the required results.

C. Description of need, if any, for additional work.

The complicated movement trajectories that we observed for the fish in our region defied categorization through simple correlation analysis. It may be possible to at least probabilistically describe the movements that we observed. We intend to work with Dr. Fred Page, of the Canadian Department of Fisheries and Oceans, who has developed a finite element model for the tidal current systems in this region. We will compare our observed course tracks to those which his model would predict for particles released at the same place and times, to see if we can develop a significant explanatory capability for these movements based on water currents alone. We also believe that releasing fish at night versus during the day may also affect their initial course tracks, with fish released at night behaving as passive objects until it becomes light enough for them to orient, whereas those released during the day would be able to take up and hold stations while they oriented to their new reality. This will also be explored through the modeling exercise.

References

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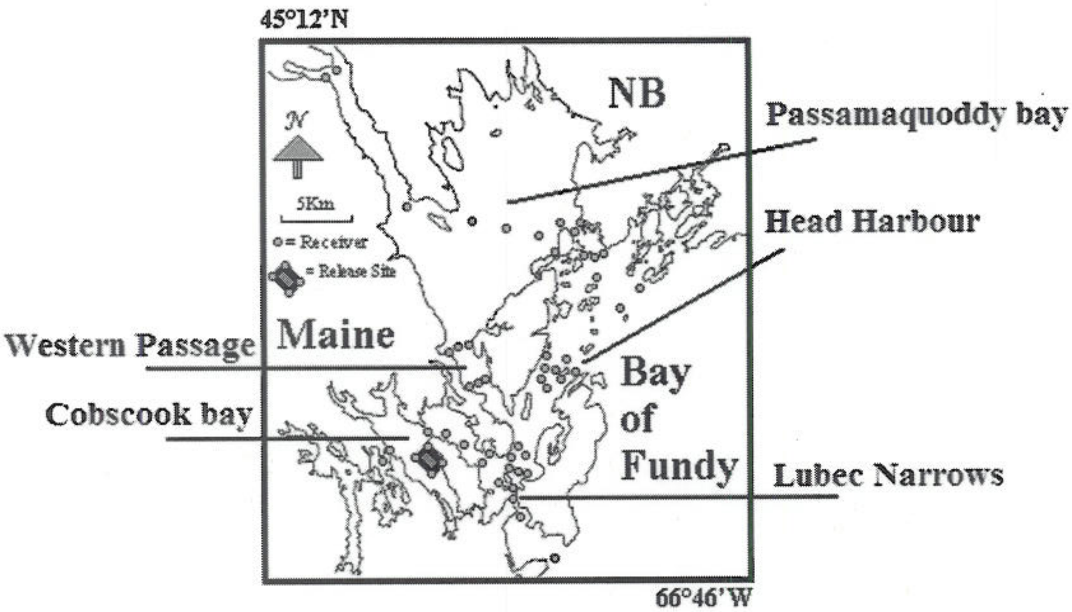
Figure 1. Map of the study area, showing the locations of:

A) Cobscook Bay release site, and concentration of inshore coastal receivers.



B). Rivers with receivers to monitor for escapees entering for spawning. The rivers were: 1, Annapolis; 2, Cornwallis; 3, Gaspereau; 4, St. Croix; 5, Kennetcook; 6, Shubenacadie; 7, Stewiacke; 8, Salmon; 9, North; 10 Chiganois; 11, Debert; 12, Folly; 13, Great Village; 14, Portapique; 15, Bass; 16, Economy; 17, Harrington; 18, Parrsboro; 19, Diligent; 20, Apple; 21, Hebert; 22, Maccan; 23, Tantramar; 24, Memramcook; 25, Petitcodiac; 26, Demoiselle; 27, West; 28, Shepody; 29, Upper Salmon; 30, Pointe Wolfe; 31 Big Salmon; 32, Irish; 33, Saint John; 34, New; 35, Pocologan; 36, Magaguadavic; 37, Digdeguash; 38, Waweig; 39, East Machias; 40, Machias.

The insert box is the area of the coastal inshore receiver arrays.

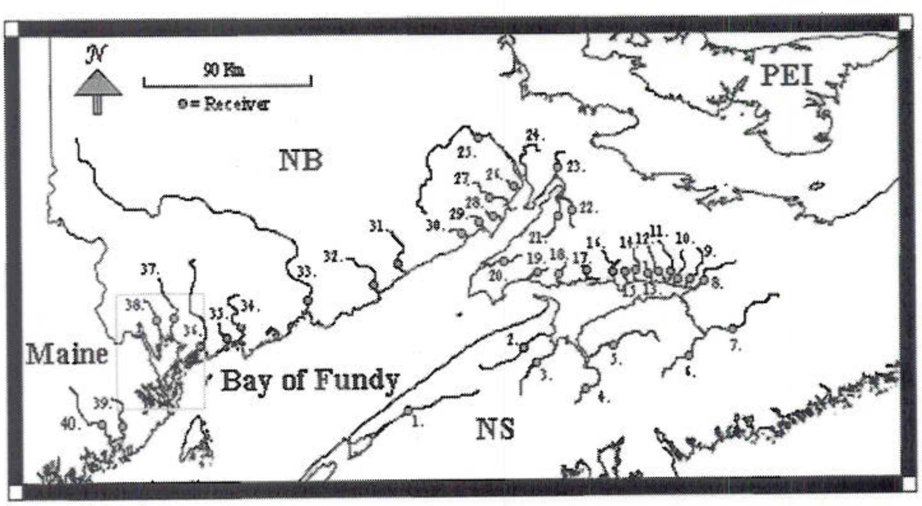
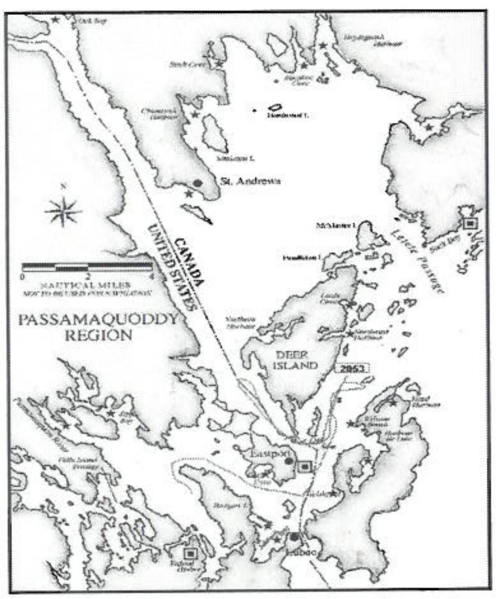


Figure 2. Course tracks for two fish. A) an individual that moved directly through the coastal zone out to the Bay of Fundy, and B) a fish that apparently became entrained in coastal currents.

A).

B.



VII. Evaluation

A. Describe the extent to which the project goals and objectives were attained. This description should address the following:

1. Were the goals and objectives attained? How? If not, why?

The goals of the project were attained.

2. Were modifications made to the goals and objectives? If so, explain.

There were no modifications to the goals and objectives.

B. Dissemination of Project results:

Explain, in detail, how the project results have been, and will be, disseminated.

We targeted communicating the results at those who had important stakes in the project. Results were disseminated by:

1) An oral presentation of initial results to the World Aquaculture Society Annual meeting in March 2004.
2) A working document submitted to the International Council for the Exploration of the Seas (ICES) Working Group for North Atlantic Salmon (F. Whoriskey, P. Brooking, G. Doucette, and S. Tinker 2004. Preliminary results from sonic tracking of experimentally escaped farmed salmon in the Bay of Fundy region. Working Paper 01, ICES WGNAS, 29 March to 8 April 2004, Halifax NS, Canada).
3) An oral presentation of the final results to the joint ICES/North Atlantic Salmon Conservation Organization symposium "Interactions between aquaculture and wild stocks of Atlantic salmon and other diadromous fish species: Science and management, challenges and solutions", in October 2005.
4) Submission of the research results in October 2005 to the ICES Journal of Marine Science for peer review and subsequent publication.
5) A piece to be published in the Spring 2006 issue of the Atlantic Salmon Journal.
6) Required interim reports for the S-K grants.